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Land Cover Mapping and Change in the Glacial Habitat Restoration Area of Wisconsin, 1990-2012

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Abstract

Remote sensing allows for mapping land cover across large areas accurately and efficiently, which is an essential component of the Glacial Habitat Restoration Area (GHRA) program. The GHRA covers 558,879 acres (2,262 km^2) in east-central Wisconsin, and was initiated with the goal of increasing critical grassland and wetland habitat for wildlife. We classified the land cover of 1,570,814 acres (6,357 km^2) in and around the GHRA using data from Landsat 7 ETM+ images for six dates between April and September 2012 with a Support Vector Machine algorithm. We used a multi-temporal image, with 60 stacked bands that incorporated spectral, Normalized Difference Vegetation values, and Tasseled Cap Transformation bands. We used 2,543 reference sites for training and K-class, cross-validation accuracy assessment. The 15-class classification had an overall accuracy of 81.4%, which increased to 85.7% when the data were consolidated into eight classes. Grasslands and wetlands had User's Accuracy of 81.0% and 89.2%, respectively, in the eight-class classification. We found 83.9% agreement between the grassland class and other GIS data sources of grasslands within the study area using overlay analyses. We smoothed the resulting classification with a 3x3 majority filter post-processing for application. We documented changes in land cover composition between the eight-class classification in 2012 and an earlier classification derived from Landsat 4 TM images for the area in 1990, prior to the start of the GHRA program. From 1990 to 2012, we found gains in coverage of grassland, cattail (*Typha spp.*), and total wetlands inside the GHRA (+1.3%, +2.0%, and +5.8%, respectively) compared to the adjacent control area (-0.1%, -1.6%, and +3.7%, respectively). Over 22 years, the coverage of forest and row crops increased in both the GHRA (+1.6% and +1.4%, respectively) and control areas (+4.5% and +2.2%, respectively), while coverage of non-row agriculture declined in both the GHRA (-7.7%) and control areas (-8.0%). Within the GHRA, grasslands were gained on state and federal lands (+6,787 acres) and through U.S. Department of Agriculture (USDA) set-aside programs (+7,125 acres). However, 6,893 acres of grassland were lost on private land outside these government programs for a net gain of 7,091 acres of grassland, which was 65% below the GHRA goal of increasing grasslands by 20,000 acres. Short-term USDA contracts through the Conservation Reserve Program (CRP) worked to restore grasslands for many years, but ultimately proved an unreliable tool to compete with market forces of agriculture. The GHRA goal of having 38,600 acres of grassland on the landscape, however, was exceeded in both 1990 and 2012 when hydric grasslands were included, mainly because of grassland scattered on private lands, which were unaccounted for using tabular file data. Within the GHRA, wetlands composed of shrubs, cattail, and open water were gained on state and federal lands (+4,673 acres) and through USDA program lands (+1,783 acres); this fell short of the GHRA restoration goal of 11,000 acres. Wetland gains on private land outside of these government programs (+11,288 acres), however, exceeded government efforts and the GHRA goal by 61%, an unexpected finding. Evaluation of wetland quality was compromised by the resolution used in remote sensing. Summarizing grassland gains of the CRP using contract data was problematic compared to using remote sensing output. Only half the acreage of GHRA land under CRP contracts targeted to establish grassland was classified as grass cover from the satellite in 1990. Conversely, CRP contracts in 2012 underestimated grassland area compared to that classified as grassland using remote sensing. After 22 years, we were unable to affect our planned changes in grassland coverage at a landscape scale with public land practices alone within this working agricultural environment. Federal farm policy and socio-economic factors overwhelmed state and federal restoration efforts at this broad scale. Our study emphasizes how remote sensing can be a valuable tool for understanding landscape-scale shifts in vegetation and trends in conservation program land cover, which can guide grassland and wetland conservation.

Contents

Cover photo: GHRA planting, Steve Easterly, Wisconsin DNR.

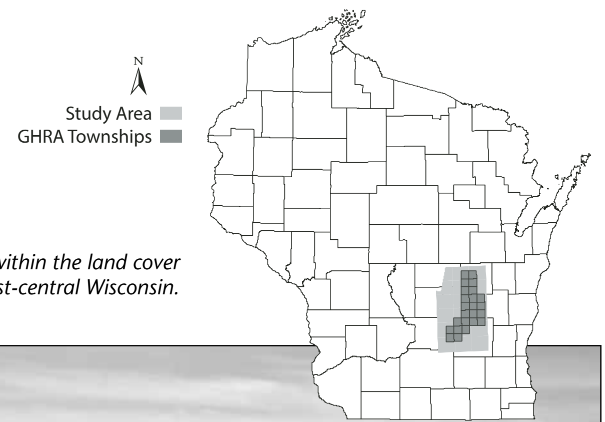


Figure 1. *GHRA located within the land cover classification study area in east-central Wisconsin.*

Introduction

The land cover of a region includes habitat types that are critical to the survival and persistence of wildlife species. Loss of these critical habitats can lead to wildlife population declines, which often prompt conservation agencies to restore and manage the critical habitat (Herkert et al. 1996, Fletcher and Koford 2003). Understanding past and current states of the landscape is an important basis for restoration management and evaluation. Manually visiting and mapping land cover at the broad scale needed for population restoration, however, is labor intensive and financially unfeasible. The availability and use of remotely sensed data, such as satellite imagery, allows large areas of the landscape to be evaluated and mapped frequently in a time- and cost-efficient manner (Castillejo-Gonzalez et al. 2009, Liu 2011).

The Glacial Habitat Restoration Area (GHRA) program is an attempt by the Wisconsin Department of Natural Resources (Wisconsin DNR) and conservation partners to increase critical grassland and wetland habitat on a landscape-scale by creating a patchwork of suitable habitat over a broad area, as opposed to concentrated habitat in smaller, dispersed sites (Crossley et al. 1990, Polzer 1992, Wisconsin DNR 2013b). By restoring grasslands and wetlands in a pattern that optimally will benefit grassland birds within an active agricultural landscape, the Wisconsin DNR hopes to reverse the decline of many grassland and wetland wildlife species that has taken place in recent decades (Gatti et al. 1994).

Specific goals of the GHRA were established from tabular data available in offices of the Wisconsin DNR, U.S. Fish and Wildlife Service (USFWS), and U.S. Department of Agriculture (USDA) for the Conservation Reserve Program (CRP), prior to availability of geographic information system (GIS) spatial data. The goals were to restore 11,000 acres of drained wetlands and establish grassland nest cover so that 38,600 acres of grassland would exist within the GHRA project area. This grassland goal was further defined to require only 20,000 acres of new grassland restorations because it was believed that 18,600 acres of grassland nest cover already existed (Crossley et al. 1990). The grassland goal was ambiguous as to whether it meant only uplands or would also include hydric soils (wet meadows), upon which many acres of nest cover and croplands exist. The "upland" adjective was occasionally used in the environmental impact statement (Crossley et al. 1990) when describing the nest cover goal, yet sedge meadows were also mentioned as acceptable habitat for nest cover, and the GHRA management guidelines included nest cover on hydric soils. Nearly all the grassland cover planted in

DNR FILE

the GHRA program was a mix of warm season grasses, but they were often planted on hydric soils. With the advent of GIS layers of soils it became possible to separate out upland and hydric grasslands after the fact (Richardson and Gatti 1999, Galbraith et al. 2003).

We used land cover mapping via remote sensing to establish the baseline of pre-restoration conditions in the GHRA (Polzer 1992) and evaluate progress toward program goals (this study). Landsat satellite imagery offers 30-meter resolution of spectral bands that are well-suited for land cover mapping on this broad scale (Smith and Fuller 2001, Wardlow et al. 2007). The overpass frequency for Landsat 7 of 16 days (NASA 2011a) allows for vegetation phenology changes to be evaluated for improved land cover identification by utilizing multiple images taken throughout the growing season (Wolter et al. 1995, Lunetta and Balogh 1999, Oetter et al. 2000). Restrictions on the timing of this study (fieldwork in 2012) precluded using data from the recently launched Landsat 8.

Our research objectives were to:

1) create a map of land cover present in and around the GHRA in 2012 using Landsat 7 data,
2) quantify land cover changes in the study area over the past 22 years by comparing the 2012 map with a previous land cover map developed from Landsat 4 data in 1990, and
3) evaluate the contributions of a variety of state, federal, and private lands toward gains (or losses) of grasslands and wetlands.

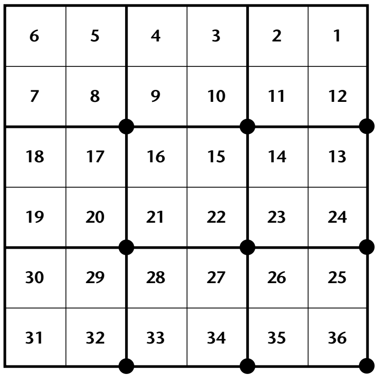


Figure 2. *Location plan for systematic collection of reference data points in a survey township. Large circles indicate reference data location intersection among numbered sections.*

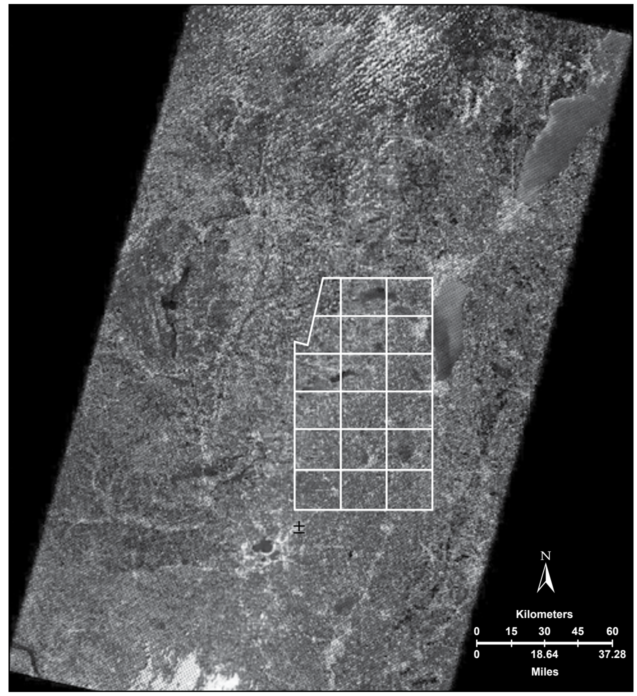


Figure 3. *Mosaic of Landsat 7 ETM+ scenes used in classification, with study area indicated.*

Methods

Study Area

The GHRA covers 558,879 acres (2,262 km^2) in 24 townships of Columbia, Dodge, Fond du Lac, and Winnebago counties in east-central Wisconsin (Figure 1). The study area for mapping land cover covered 1,570,814 acres (6,357 km^2), composed of the core GHRA and surrounding control area. The study area used the exact boundary Polzer (1992) used in his land cover classification. The area lies within the Southeast Glacial Plains and Central Sand Hills ecological landscapes (Pohlman et al. 2006), an area of gently rolling topography from past glaciations and soils dominated by silt loams but ranging from sandy to clay (Link 1973). Dominant land use of the area is dairy farming and cash grain cropping with a mix of small woodlots, wetlands, shallow lakes, and residential/urban development (Pohlman et al. 2006, Wisconsin DNR 2012). Public lands inside the GHRA include 16,510 acres of Horicon National Wildlife Refuge (HNWR), nine USFWS waterfowl production areas (WPAs) totaling 4,081 acres, and six large state properties totaling 10,159 acres (Wisconsin DNR 2013c). Public lands within the study area but outside the GHRA (i.e. the control area) include 4,842 acres of HNWR, seven WPAs totaling 906 acres, and six large state properties totaling 39,756 acres. Horicon Marsh, divided between state and federal ownership, is one of the largest freshwater cattail (*Typha spp.*) marshes in the United States and has several wetland impoundments that are managed to provide wetland habitat for a variety of waterfowl and other marsh birds (USFWS 2013).

Land Cover Classes and Reference Data Collection

The land cover classes for this study included a variety of agricultural, developed, and natural habitat types (Table 1). The original classification included reference points for 15 classes, but we consolidated several of these classes because our main interests were identification of grasslands and wetlands, and not cropland or forest types. We completed final land cover evaluations using an eight-class classification scheme, whereby five classes were consolidations of the original reference data (Table 2). Post-classification overlay, with a hydric soils layer using ArcGIS 10.1 software (Environmental Systems Research Institute, Inc., Redlands, CA), allowed for the subdivision of the forest class into wet forest and upland forest subclasses, and the subdivision of the grassland class into hydric grass and upland grass subclasses; however, these sub-classes were not evaluated in the accuracy assessments.

We collected reference data for classification training and accuracy assessment in the field during June and July 2012, primarily using systematic sampling in the 24 townships of the GHRA. We divided each township into nine equal blocks of 4 mi^2 based on the Public Land Survey System (NationalAtlas.gov 2013). A field crew visited the road intersection nearest to the southeast corner of each block (Figure 2) and delineated on orthophotos the land cover present in each of the four cardinal directions at these intersections; this yielded 216 intersections for sampling. We collected additional reference data via roadside visits in July 2012 for classes under-represented by the systematic sampling; we identified target class sites on orthophotos, and then verified and delineated their land cover in the field. We also collected reference data from digital land cover (primarily deciduous, cattail, developed, and grassland classes) mapped in the field during July-August 2012 for a Wisconsin DNR duck research study and during May 2011 for a Wisconsin DNR pheasant research study, both within the GHRA study area (R.C. Gatti, Wisconsin DNR, unpublished data). The senior author also collected reference data for land cover classes that were still under-represented in the above sampling (conifer, deciduous, water, and developed classes) by visual inspection of Landsat imagery.

We input and processed reference data with ENVI 5.0 image analysis software (Exelis Visual Information Solutions, Boulder, CO) using pixel-based regions of interest (ROI) within the identified reference sites. We chose ROI pixels located at the center of a 3-by-3 pixel group (window) of homogeneous cover. If a homogeneous window was not present, we also accepted an ROI pixel from the class having at least six of the nine pixels in the window (Hammond

Table 1. *Land cover class names and descriptions used in the GHRA study.*

	Class	General Description
Individual Classes	Soybeans	Agricultural soybean field
	Corn	Agricultural corn field
	Wheat	Agricultural wheat field
	Oats	Agricultural oat field
	Other Agriculture	Agricultural field growing various types of fruit and/or vegetable crops
	Hay	Agricultural field used for forage crops such as alfalfa
	Pasture	Agricultural field used to graze livestock
	Conifer	Forest or woodlot dominated by coniferous, needle-leaf tree species
	Deciduous[1]	Forest or woodlot dominated by deciduous, broadleaf tree species; later divided into Upland and Hydric subclasses via overlay of hydric soils
	Shrubs	Wetland dominated by shrub vegetation, with limited standing water
	Canary Grass	Wetland dominated by grass (narrow leaf) vegetation without standing water
	Idle Grass	Upland field dominated by grass vegetation and/or forbs, with little to no woody vegetation
	Cattail	Wetland dominated by cattail
	Water	Lake, large river, or wetland dominated by open water
	Developed	Area of human development, including residential, industrial, roads, or resource removal (gravel pits)
Consolidated Classes	Row Crops	A consolidated class of the Soybeans, Corn, Wheat, Oats, and Other Agriculture classes
	Non-Row Agriculture	A consolidated class of the Hay and Pasture classes
	Grassland[1]	A consolidated class of the Canary Grass and Idle Grass classes; later divided into Upland and Hydric subclasses via overlay of hydric soils
	Wetland	A consolidated class of the Shrubs, Canary Grass, and Cattail classes
	Forest	A consolidated class of the Conifer and Deciduous classes

[1]Class was subdivided in ArcGIS after primary classification, via overlay analysis.

and Verbyla 1996). Many of the developed areas had reference sites smaller than a 3-by-3 window; in these cases we manually reviewed images to identify the most representative pixel of the targeted land cover class. ROI pixels were at least three pixels away from another ROI of the same class.

Image Selection and Correction

The study area is covered by Landsat scenes from rows 29 and 30 in path 24 (Figure 3). We downloaded six dates of Landsat 7 ETM+ product level L1T images with minimal cloud cover using the U.S. Geological Survey Global Visualization Viewer server (**http://glovis.usgs.gov**): images from 9 April, 27 May, 28 June, 30 July, 31 August, and 19 September 2012. The scan line corrector (SLC) of Landsat 7 failed on 31 May 2003, leaving data gaps (approximately 22% of each scene) that need to be addressed for complete use of images after this date (NASA 2011b). We used the Neighborhood Similar Pixel Interpolator gap-fill algorithm created by Chen et al. (2011) to fill in the missing data; we used data from three other minimal cloud-cover images (from 2012) as input to iteratively fill the gaps in each image before the classification. Any clouds that were located in the gap-filled images were removed through masking.

Classification Process

We merged both scenes into a mosaic image of the study area prior to classification (Cihlar 2000) and combined six spectral bands (1 through 5 and 7) for each of the six image dates into a single 36-band image. We did not use Band 6 (thermal) in this classification. For each of the six target dates we calculated Normalized Difference Vegetation Index (NDVI) values, and Tasseled Cap Transformation (TCT) information to synergistically improve the

Table 2. *Aggregations of the 1990 and 2012 GHRA land cover classes used for land cover change evaluation.*

	2012 Class Equivalent	
1990 Class	**15-Class Map**	**8-Class Map**
Soybeans	**Soybeans**	**Row Crops**
Corn	**Corn**	
Wheat	**Wheat**	
Oats	**Oats**	
Orchard Peas Urban Pervious	**Other Agriculture**	
Hay	**Hay**	**Non-Row Agriculture**
Upland Grazed Wetland Grazed	**Pasture**	
Upland Conifer	**Conifer**	**Forest**
Upland Deciduous Wet Deciduous	**Deciduous**	
Shrubs	**Shrubs**	**Shrubs**
Sedges Canarygrass	**Canarygrass**	**Grassland**
Old Field Warm Cool Forbs	**Idle Grass**	
Cattail Emergents	**Cattail**	**Cattail**
Urban Roads Urban Impervious Gravel	**Developed**	**Developed**
Water	**Water**	**Water**

classification process (Dymond et al. 2002, Champagne et al. 2005). NDVI values can identify differences between various crops by exploiting variations among phenological characteristics and planting schedules in agricultural landscapes (Wardlow et al. 2007), while TCT is used to reduce Landsat's spectral information into primary features of brightness, greenness, and wetness (BGW) and condense the spectral variability into half the number of channels (Crist et al. 1986, Vorovencii 2007). We finally combined the TCT BGW bands with the 36-band spectral images and six NDVI bands to create a single, multi-temporal image with 60 bands for classification.

We evaluated separability between the target classes' ROI by calculating their Jeffries-Matusita distances (JMD). Values of JMD range from 0 to 2 for each pair of classes, with a larger value indicating a greater distinction between those classes (Wardlow et al. 2007). High separability is an indicator of overall classification quality and assists in the selection of optimal bands for classification (Koukoulas and Blackburn 2001). When spectral bands 1 through 5 and 7 were combined with NDVI bands, a JMD over 1.9 was achieved for all classes able to be evaluated.

We used a linear Support Vector Machine (SVM) algorithm and the identified ROI data to classify the 60-band, stacked image into the target land cover classes. SVM uses hyperplanes and the reference data to determine the most appropriate classification (Cristianini and Shawe-Taylor 2000, Mountrakis et al. 2011). Advantages of SVM are its ability to work well:

1) in heterogeneous and agricultural landscapes (Melgani and Bruzzone 2004),
2) with smaller training data sets and noisy data bands (Foody and Mathur 2004a, Mathur and Foody 2008),
3) with complex classes, and
4) more accurately than other classification algorithms in many situations (Huang et al. 2002, Foody and Mathur 2004b).

Accuracy Assessment and Land Cover Comparisons

All accuracy assessments were completed in ENVI using unconverted, unfiltered raster files. We created confusion matrices for each classification to evaluate the Producer's and User's Accuracy for each class and overall accuracy of the classification (Foody 2002, Skirvin et al. 2004). Producer's Accuracy evaluates how well a classification captures errors of omission, where a point was not included in the class it should have been. User's Accuracy reflects errors of commission, where a point was included in a class when it should not have been. These metrics are related, as an error of commission for one class will be an error of omission for another. We also calculated the Kappa coefficient to evaluate the classification results compared to chance agreement (Congalton et al. 1983, Fitzgerald and Lees 1994); a Kappa coefficient >0.4 is considered "good" and a value >0.75 indicates "excellent" results compared to what chance would have provided (Landis and Koch 1977). To assess final accuracy of the classifications we used K-class cross-validation (Muchoney and Strahler 2002, Knorn et al. 2009). We randomly divided the ROI for each class into five sub-sets consisting of 20% of the ROI for that class. Four of the sub-sets were used to develop the classification and the remaining sub-set was used to evaluate accuracy. This was repeated five times (runs), with a different sub-set of ROI from each class used for accuracy assessment each time. The final accuracy (overall and per class) was calculated as the average of the five runs.

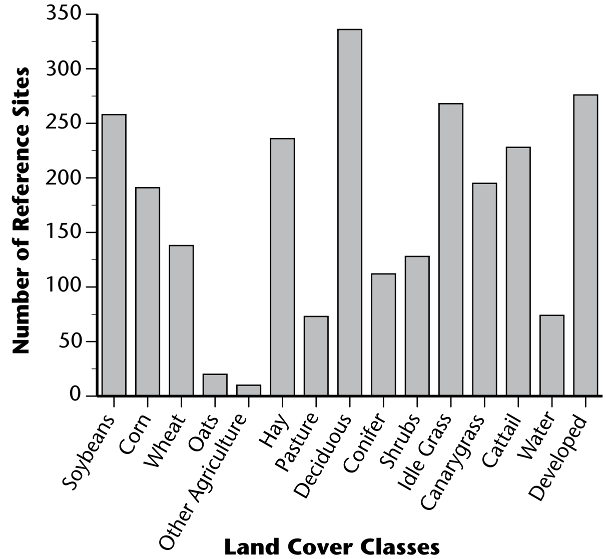
The final map was created using all of the ROI training sites (Burman 1989, Knorn et al. 2009). We smoothed the appearance of the resulting classifications with a 3x3 majority filter prior to exporting the classification to ArcGIS for application.

We further evaluated the grassland class because of the importance of grasslands to the GHRA program. We selected out the grassland class from the eight-class 2012 classification and overlaid it in ArcGIS with three recent GIS data sources of land cover within the study area that included grasslands (i.e. "known grass") to determine the percent agreement between the 2012 grassland class and the "known grass" area. The three GIS data sources of "known grass" were:

1) a land cover map of HNWR created from ground-truthing in 2005 (J. Krapful, USFWS, unpublished data),
2) a land cover map of selected state wildlife lands created by manual (field) mapping in 2008 and 2012 for a Wisconsin DNR duck research study within the GHRA study area (R.C. Gatti, Wisconsin DNR, unpublished data), and
3) a land cover map of 16 WPA created by field mapping in 2012 (J. Lutes, USFWS, unpublished data). We excluded any "known grass" areas previously used as ROI in the 2012 satellite classification to ensure independence of sampling.

Comparison of land cover change over time required a cross-walk between the different classes in 1990 (Polzer 1992) and 2012 classifications (this study). We pooled many of the 27 classes from the 1990 classification into logical, aggregated classes similar to the 2012 classifications (Table 2). Because the 1990 classes of pervious, orchard, and peas did not have an equivalent in 2012, we combined them into a single class (other agriculture) in the 1990 classification. The 1990 wet deciduous class was based on deciduous forests located within wetlands, via overlay with the GIS layer of the Wisconsin Wetland Inventory (Wisconsin DNR 1992, Polzer 1992), as opposed to the overlay with hydric soils used in the 2012 classification. To standardize this class for comparison, the 1990 classes of wet deciduous, upland deciduous, and conifer were combined into a single forest class and then subdivided, based on the presence of hydric soils. The 1990 map also was found to be misaligned 60 meters north, based on parameters of the coordinate system in its GIS shapefile, and verified via overlay with GIS layers of roads and orthophotos. We shifted the 1990 map to correct the misalignment, which caused slight data loss along the study area boundary (0.02% of the total area). Additionally, the 1990 class of roads was not derived from classification, but had been "burned" into the 1990 map, using a GIS raster layer of roads, post-classification. This exaggerated the area covered by roads by making all roads at least 30 m wide (the pixel resolution). The exaggeration

Figure 4. *Number of available reference sites per class across the entire GHRA study area.*



was unrecoverable and made estimation of changes in the developed class over time problematic.

The land cover in the GHRA was further compared to evaluate change trends for each class between 1990 and 2012. For each class we summarized the percent of the landscape that was unchanged for that class in both years, and the percent that was changed to and from each other class to give a net change between each pair of classes.

In order to identify where critical habitat gains (or losses) were coming from within the GHRA, we summarized land cover changes separately on state, federal, and private lands. We clipped land cover from the 1990 and 2012 classification maps with current property boundaries for HNWR, USFWS WPAs, and Wisconsin DNR managed lands. By using 2012 boundaries, even on properties bought during the time interval, we could determine true gains in grassland and wetland habitats (e.g., a private wetland existing in 1990 that was bought in 2000 and maintained as wetland in 2012 was not considered a wetland gain). Boundaries of federal properties were made available from the USFWS (HNWR: J. Krapful, Horicon, and WPAs: J. Lutes, Portage). Boundaries of state lands acquired through fee title were available from Wisconsin DNR's managed lands GIS files (Wisconsin DNR 2013a); these state properties were evaluated separately for six large properties (Deppe Marsh, Eldorado Marsh, and Paradise Marsh wildlife areas, Brandon Marsh and Westford Marsh public hunting grounds, and the Fox Lake fisheries area) vs. remaining smaller state parcels, which were most active in habitat restoration. Boundaries of long-term easements in the GHRA were provided from Wisconsin DNR GHRA field managers (B.J. Woodbury and A.J. Wright, Wisconsin DNR, Oshkosh). Long-term easement boundaries for the USDA Wetland Reserve Program (WRP) were accessed from the National Conservation Easement Database (NRCS 2013b). Boundaries for CRP fields in 1990, 1994, and 1998 were created in GIS from USDA paper files (Gatti et al. 1994) and CRP field boundaries in 2007 were provided in GIS files by USDA (L. Cutforth, USDA Farm Service Agency, Madison). However, because the 2008 Farm Bill prohibits release of more recent spatial data for CRP (U.S. Farm Service Agency 2010), we used 2007 CRP field boundaries as best estimates of the 2012 CRP field boundaries. USDA state summaries for Wisconsin counties show declining participation in CRP since 2007 (U.S. Farm Service Agency 2013). By clipping the 2012 land cover within the 2007 CRP fields, we were able to identify fields that left the program and returned to agricultural production. For land cover change we merged CRP contracts for all conservation practices and for all years (1990 through 2007) and used this compiled area to clip out 1990 and 2012 land cover. Field boundaries for USFWS contracts in their Partner for Fish and Wildlife (PFW) program were provided in GIS files by USFWS (K. Waterstradt, USFWS, Madison). Grassland change on lands included in all programs was also evaluated between grasslands on hydric soils vs. upland soils via an overlay of the 2012 grassland class with GIS data layers of soils (NRCS 2013a).

Results

2012 Land Cover Classifications

We created 2,543 ROI across all classes and both scenes (Figure 4). The number of ROI for each class ranged from 10 (other agriculture) to 336 (deciduous). ROI came mostly from field crew reference site collection (52%) and concurrent Wisconsin DNR land cover mapping studies (39%); only 9% came from analyst image interpretation.

Overall accuracy for the 15-class classification was 81.4% with a Kappa coefficient of 0.796 (Table 3); overall accuracy among the five runs of cross-validation ranged from 78.0% to 84.2%. Producer's Accuracy ranged from 15.0% to 96.0% among classes and User's Accuracy ranged from 40.0% to 98.7%. The classes with the lowest User's Accuracy (oats, other agriculture, and pasture) also had the smallest number of ROI, suggesting that inadequate sample sizes may have contributed to the lower accuracy of these classes. The eight-class classification had a higher overall accuracy (85.7%) and Kappa coefficient (0.828) than for the 15-classes (Table 4); overall accuracy among the five runs of cross-validation ranged from 82.9% to 88.2%. Producer's Accuracy ranged from 51.4% to 95.5% among classes and User's Accuracy ranged from 71.8% to 97.3%. When comparing the two classifications, User's Accuracy improved in the eight-class classification with the consolidation of most classes (pasture to non-row agriculture =+23.2%, corn to row crops =+14.3%, hay to non-row agriculture =+12.7%, dominated by reed canary grass (*Phalaris arundinacea*) to grassland =+9.7%, and idle grass to grassland =+4.8%) but not for wheat to row crops (-5.5%), soybeans to row crops (-4.5%), or conifer to forest (-3.6%). User's Accuracy was also higher in the eight-class classification compared to the 15-class classification for some classes that were not consolidated (shrubs =+5.2%, developed =+2.1%). Differences between the two classifications in other classes were either minor (deciduous, water, and cattail) or due to inadequate sample sizes of ROI (oats and other agriculture). Additionally, the canary grass and idle grass classes were more often

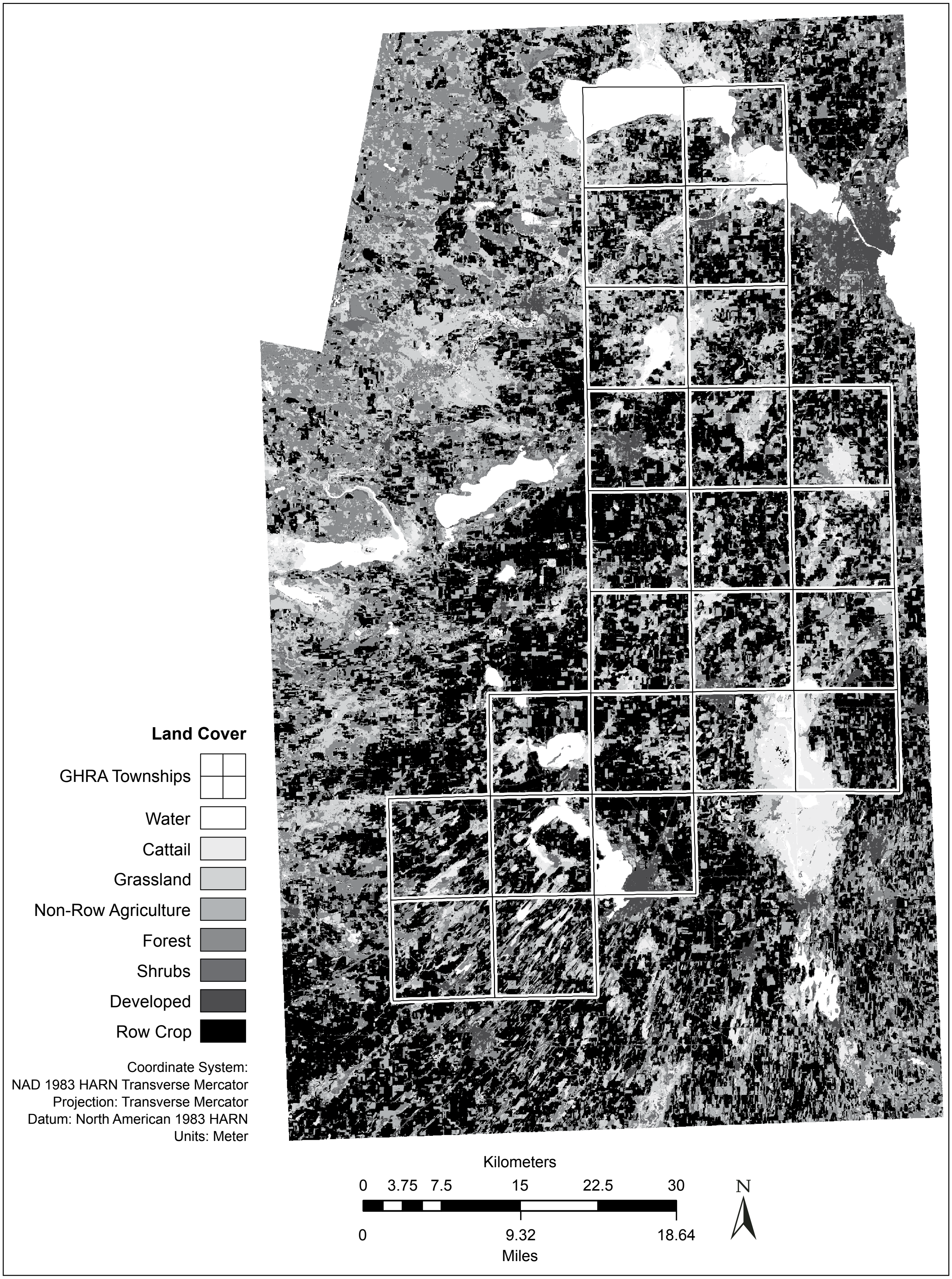


Figure 5. *Classified map of land cover in the GHRA study area, 2012.*

Table 3. *Land cover classification accuracy for 15 classes across the GHRA study area, 2012.*

Class	Producer's Accuracy	User's Accuracy
Soybeans	92.2	90.0
Corn	89.5	71.2
Oats	15.0	40.0
Wheat	79.0	91.0
Other Agriculture	20.0	40.0
Hay	67.0	62.7
Pasture	29.0	52.2
Conifer	91.9	96.4
Deciduous	95.2	91.4
Shrubs	54.5	66.6
Canarygrass	67.7	71.3
Idle Grass	85.8	76.2
Cattail	86.4	87.2
Water	96.0	98.7
Developed	89.2	91.9
Overall accuracy	**81.4**	
Kappa coefficient	**0.796**	

Table 4. *Land cover classification accuracy for eight classes across the entire east-central Wisconsin study area, 2012.*

Class	Producer's Accuracy	User's Accuracy
Row Crops	94.2	85.5
Non-Row Agriculture	64.4	75.4
Forest	95.5	92.8
Shrubs	51.4	71.8
Grassland	87.9	81.0
Cattail	83.8	87.4
Water	94.7	97.3
Developed	85.9	94.0
Overall accuracy	**85.7**	
Kappa coefficient	**0.828**	

confused with each other (46% of misclassifications) than any other land cover class, hence the improvement in accuracy when consolidated into a single grassland class.

Our overlay analysis between the grassland class (eight-class classification) with areas of "known grass" in other recent land cover maps lends additional credibility to the high accuracy of the grassland class. The area classified as grassland in 2012 and "known grass" agreed 81.9% for the 2005 HNWR data, 84.7% for the WPA data, and 85.1% for the Wisconsin DNR duck study data; the simple mean of these three estimates was 83.9% agreement, which is comparable to the User's Accuracy for grassland (mean=81.0%, range=78.3% to 84.5%) in the 2012 classification. Overlay analyses between the canary grass and idle grass classes from the 15-class classification and these "known grass" data layers gave further indication that there was confusion between wet meadow and upland grass types. We found similar agreement with all types of "known grass" for canary grass (85.0%) and idle grass (85.7%). But there was 13.1% confusion between canary grass and "known" upland grasses, and 11.7% confusion between idle grass and "known" wet meadow, lending additional support for consolidating the canary grass and idle grass classes into a single grassland class.

The GIS data layer created from the 15-class classification was used to summarize the area of each land cover class in the GHRA, control area, and entire study area (Table 5). The percent composition of the GHRA was similar to that in the control area for most of the 15 classes. Only four classes showed a difference of over 2% between these two areas. The GHRA had a greater coverage of corn (+5.7%) and soybeans (+2.5%), but a lower coverage of deciduous (-8.3%) and idle grass (-3.6%) compared to the control area in 2012. Corn was the most prevalent cover type across the entire area (23%), followed by hay (13%), deciduous (13%), and soybeans (10%). The low occurrence of pasture, oats, and other agriculture helps explain the difficulty of finding adequate ROI for these classes.

After consolidating the reference data into eight classes and classifying the image (Figure 5), only three classes showed a difference of at least 2% between the GHRA and control areas (Table 6). The GHRA had a greater coverage of row crops (+7.9%) and cattail (+2.0%), but a lower coverage of forest (-9.4%), compared to the control area. When forest and grassland were subdivided into upland and hydric areas using GIS overlay analyses based on hydric soils, the GHRA had lower coverage of upland forest (-6.6%), wetland forest (-2.8%), and upland grass (-2.0%) compared to the control. Total wetland cover (consisting of water, cattail, hydric grass, shrubs, and wetland forest classes) was similar between the GHRA (31.0%) and the control area (29.7%) in 2012. The wetland type excluding forest and grass cover (only including water, cattail, and shrub classes) was more abundant in the GHRA (15.2%) than in the control area (12.3%). Row crops were the most abundant land cover across the total study area (41%), followed by grassland (15%) and forest (14%).

Land Cover Changes, 1990-2012

We found several changes of at least 2% between the land cover composition of the entire study area in 2012 with that in 1990 (Table 7). There were decreases in the coverage of non-row agriculture (-7.9%) and upland grass (-2.0%), and increases in coverage of forest (+3.4%), hydric grass (+2.4%), and upland forest (+2.0%) classes over the 22 years. We also found minor increases in the coverage of row crops (+1.9%), shrubs (+1.8%), wetland forest (+1.5%), and developed (+1.3) classes between 1990 and 2012.

Within the GHRA, the coverage of non-row agriculture decreased 7.7%, while the coverage of cattail increased 2.0% from 1990-2012 (Table 8). We also found minor increases in coverage of shrubs (+1.8%), hydric grass (+1.8%), forest (+1.6%), row crops (+1.4%), and total grassland (+1.3%) over 22 years. In the control area, there were decreases in non-row agriculture (-8.0%) and upland grass (-2.7%) coverage and increases in forest (+4.5%), hydric grass (+2.7%), upland forest (+2.6%), developed (+2.3%), and row crops (+2.2%) coverage from 1990 to 2012. We also found minor decreases in coverage of cattail (-1.6%) and water (-1.1%), and minor increases in coverage of wetland forest (+1.9%) and shrubs (+1.8%) in the control area.

The per-class change comparisons between 1990 and 2012 showed that 67% of the GHRA landscape was the same class in both years (Table 9). The overall loss in the area of water came mainly from the spread of cattails into

Table 5. *Land cover area for 15 classes across the GHRA vs. control area, 2012.*

	GHRA		Control Area		Total Study Area	
Class	**Acres**	**% of Area**	**Acres**	**% of Area**	**Acres**	**% of Area**
Corn	147,052	26.3	208,463	20.6	355,515	22.6
Soybeans	65,134	11.6	92,362	9.1	157,497	10.0
Wheat	19,216	3.4	25,692	2.5	44,908	2.9
Oats	159	0.0	887	0.1	1,046	0.1
Other Agriculture	71	0.0	232	0.0	302	0.0
Hay	74,783	13.4	126,757	12.5	201,540	12.8
Pasture	2,679	0.5	7,319	0.7	9,999	0.6
Conifer	2,572	0.5	17,216	1.7	19,788	1.3
Deciduous	41,404	7.4	158,875	15.7	200,279	12.8
Shrubs	18,394	3.3	40,538	4.0	58,932	3.8
Canarygrass	47,879	8.6	67,682	6.7	115,561	7.4
Idle Grass	28,640	5.1	88,362	8.7	117,002	7.4
Cattail	36,577	6.5	47,088	4.7	83,666	5.3
Water	34,461	6.2	45,682	4.5	80,143	5.1
Developed	39,858	7.1	84,778	8.4	124,635	7.9
Total	**558,879**	**100.0**	**1,011,935**	**100.0**	**1,570,814**	**100.0**

Table 6. *Land cover area for eight classes across the GHRA vs. control area, 2012.*

	GHRA		Control Area		Total Study Area	
Class	**Acres**	**% of Area**	**Acres**	**% of Area**	**Acres**	**% of Area**
Row Crops	257,121	46.0	385,209	38.1	642,330	40.9
Non-Row Agriculture	55,393	9.9	96,167	9.5	151,560	9.6
Forest	44,471	8.0	175,571	17.4	220,042	14.0
Upland Forest[1]	*17,492*	*3.1*	*98,633*	*9.8*	*116,125*	*7.4*
Wetland Forest[1]	*26,979*	*4.8*	*76,938*	*7.6*	*103,917*	*6.6*
Shrubs	16,294	2.9	37,390	3.7	53,684	3.4
Grassland	82,145	14.7	157,192	15.5	239,337	15.2
Upland Grass[1]	*20,421*	*3.7*	*57,510*	*5.7*	*77,931*	*5.0*
Hydric Grass[1]	*61,724*	*11.0*	*99,682*	*9.9*	*161,406*	*10.3*
Cattail	34,214	6.1	41,723	4.1	75,937	4.8
Water	34,194	6.1	45,087	4.5	79,281	5.0
Developed	35,047	6.3	73,596	7.3	108,643	6.9
Total[2]	**558,879**	**100.0**	**1,011,935**	**100.0**	**1,570,814**	**100.0**

[1] Classes created in ArcGIS after ENVI classification based on presence of hydric soils.

[2] Total of eight primary classes only.

DNR FILE

Table 7. *Land cover composition (% of area) for the entire GHRA study area, 1990*[1] *and 2012.*

Class	**1990**	**2012**	**Change in % 2012-1990**
Row Crops	39.0	40.9	+1.9
Non-Row Agriculture	17.6	9.7	-7.9
Forest	10.6	14.0	+3.4
Upland Forest[2]	*5.4*	*7.4*	*+2.0*
Wetland Forest[2]	*5.1*	*6.6*	*+1.5*
Shrubs	1.6	3.4	+1.8
Grassland	14.8	15.2	+0.4
Upland Grass[2]	*6.9*	*5.0*	*-2.0*
Hydric Grass[2]	*7.9*	*10.3*	*+2.4*
Cattail	5.1	4.8	-0.3
Water	5.7	5.0	-0.7
Developed	5.6	6.9	+1.3
Total	**100.0**	**100.0**	

[1] From Polzer (1992).

[2] Classes created in ArcGIS after ENVI classification based on presence of hydric soils.

Table 8. *Land cover composition of the GHRA and control area, 1990[1] and 2012, and change in % of each area.*

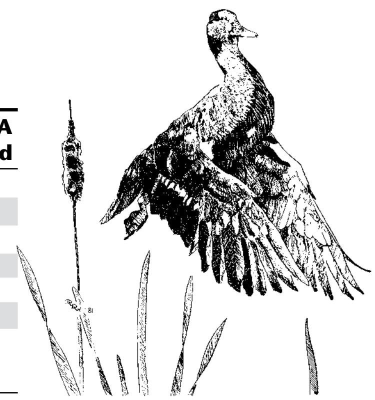
	GHRA			Control Area		
Class	**1990**	**2012**	**% Change**	**1990**	**2012**	**% Change**
Row Crops	248,930	256,988	+1.4	362,627	385,209	+2.2
Non-Row Agriculture	98,354	55,364	-7.7	177,400	96,167	-8.0
Forest	35,476	44,448	+1.6	130,448	175,571	+4.5
Upland Forest[2]	*12,702*	*17,483*	*+0.9*	*72,460*	*98,633*	*+2.6*
Wetland Forest[2]	*22,774*	*26,965*	*+0.8*	*57,988*	*76,938*	*+1.9*
Shrubs	6,269	16,286	+1.8	19,456	37,390	+1.8
Grassland	75,054	82,145	+1.3	157,183	157,192	-0.1
Upland Grass[2]	*23,659*	*20,410*	*-0.6*	*84,953*	*57,510*	*-2.7*
Hydric Grass[2]	*51,395*	*61,692*	*+1.8*	*72,231*	*99,682*	*+2.7*
Cattail	22,991	34,196	+2.0	57,459	41,723	-1.6
Water	37,698	34,176	-0.6	56,310	45,087	-1.1
Developed	33,817	35,029	+0.2	50,262	73,596	+2.3
Total	**558,879**			**1,011,935**		

[1] From Polzer (1992).
[2] Classes created in ArcGIS after ENVI classification based on presence of hydric soils.

Table 9. *Source of land cover class changes, between 1990 and 2012 in the GHRA (in net of the change from in % of area[1] between each pair of land cover classes).*

	% of GHRA Changed in 2012 to					% of GHRA
GHRA Class in 1990	**Water**	**Cattail**	**Shrubs**	**Grass**	**Forest**	**Unchanged**
Water	X	**+0.6**	-0.0	-0.0	+0.1	5.6
Cattail	**-0.6**	X	-0.1	**-0.5**	-0.1	2.6
Shrubs	+0.0	+0.1	X	**-1.0**	-0.3	0.2
Grassland	-0.0	**+0.5**	**+1.0**	X	+0.2	5.2
Forest	-0.1	+0.1	+0.3	-0.2	X	3.2
Agriculture[2]	+0.0	**+0.6**	**+0.7**	**+2.8**	**+1.3**	47.9
Developed	-0.0	+0.1	+0.0	+0.1	+0.4	2.4
Total Net Change	**-0.7**	**+2.0**	**+1.8**	**+1.3**	**+1.6**	**Total 67.1**

[1] Per-class comparison.
[2] Combines row crops and non-row agriculture classes.



former water areas. Cattail wetlands had a net expansion into every land cover class, but their gain came mainly (80% of gains) from their invasion into former areas of water, grassland, and agriculture. The gain in shrubs came mainly (95% of gains) from their invasion into grassland and agriculture areas since 1990. Changes in grasslands resulted from losses (expansion of shrubs and cattails into former grasslands) that were offset by a large gain (grassland restoration) on former agriculture lands. The increase in forest coverage came mainly from growth on former agricultural and developed lands.

The net differences between land cover changes in the GHRA and control areas suggest how restoration and management practices in the GHRA may have altered the trajectory of land cover change from what likely would have happened (i.e. seen on the surrounding control area) had the program not been in place. Impacts were positive for cattail (coverage increased in the GHRA and decreased in the control area, net change=+3.6%) and upland grass (loss in coverage was not as great in the GHRA as in the control area, net change=+2.2%). Net changes were negative (gain in coverage was less in the GHRA than in the control area) for forest (-2.9%) and developed (-2.1%) classes. Minor net changes were also found for upland forest (-1.7%), wetland forest (-1.1%), and total grassland (+1.3%). There were also positive impacts for total wetlands (+2.1%) and for pooled wetland types excluding forest and grass cover (+4.1%).

GHRA Accomplishments

The change in total grass coverage from 1990 to 2012 in the GHRA (+1.3%) amounts to a gain of 7,091 acres, which comes from a gain of 10,329 acres of hydric grass and a loss of 3,238 acres of upland grass (Tables 10 and 11). The change in total wetland coverage over these 22 years in the GHRA (+5.8% of the landscape, Table 8) amounts to a gain of 32,278 acres (Table 12). Another measure of wetland gain is to exclude forested wetlands, because they are not the target wetland type for restoration in Wisconsin, and hydric grass, which is already included in grass gains above; there was a gain of 17,744 acres over time for these remaining “target wetland types” (cattail, water, and shrub wetlands; Table 13). A third measure of wetland types (only cattail and water classes) showed a gain 7,719 acres over time in the GHRA (Table 14). The gains of each of these critical habitat types in the GHRA varied among the partner programs, working towards the restoration goals.

Table 10. *Abundance and change of total grassland acres among categories of government ownership or programs within the GHRA, 1990 and 2012.*

Agency or Program	1990	2012	Change[1]
Wisconsin DNR fee title – 6 large properties	2,316	2,706	390
Wisconsin DNR fee title – small properties	2,420	6,977	4,557
Wisconsin DNR easements	2,010	3,221	1,211
USFWS fee title - HNWR	2,814	2,640	-174
USFWS fee title - WPAs	1,179	1,982	803
USFWS contracts - PFW	65	136	72
USDA easements - WRP	1,081[2]	2,552	1,471
USDA contracts - CRP	5,967	11,620	5,654
Remaining Private Lands	57,203	50,310	-6,893
Total	**75,054**	**82,145**	**+7,091**

[1] Change in terms of gain in 2012 (i.e. 2012 acres–1990 acres).
[2] The WRP did not exist in 1990. This number indicates grassland present in 1990 on lands that would become part of the WRP.

Table 11. *Change in grassland acres among categories of government ownership or programs within the GHRA, 1990 to 2012[1].*

Agency or Program	Upland Grass	Hydric Grass	Total Grass
Wisconsin DNR fee title – 6 large properties	572	-182	390
Wisconsin DNR fee title – small properties	1,743	2,814	4,557
Wisconsin DNR easements	688	523	1,211
USFWS fee title - HNWR	81	-255	-174
USFWS fee title - WPAs	309	493	803
USFWS contracts - PFW	26	46	72
USDA easements - WRP	93	1,378	1,471
USDA contracts - CRP	1,915	3,738	5,654
Remaining Private Lands	-8,665	1,774	-6,893
Total	**-3,238**	**+10,329**	**+7,091**

[1] Change in terms of gain in 2012 (i.e. 2012 acres–1990 acres).

Table 13. *Abundance and change of target wetland (cattail + water + shrub classes) acres among categories of government ownership or programs within the GHRA, 1990 and 2012.*

Agency or Program	1990	2012	Change[1]
Wisconsin DNR fee title – 6 large properties	4,645	5,784	1,139
Wisconsin DNR fee title – small properties	1,283	2,282	999
Wisconsin DNR easements	1,293	2,265	972
USFWS fee title - HNWR	12,098	12,894	796
USFWS fee title - WPAs	778	1,525	747
USFWS contracts - PFW	16	36	20
USDA easements - WRP	399	1,965	1,566
USDA contracts - CRP	840	1,057	217
Remaining Private Lands	45,606	56,894	11,288
Total	**66,958**	**84,702**	**+17,744**

[1] Change in terms of gain in 2012 (i.e. 2012 acres–1990 acres).

Table 12. *Abundance and change of total wetland acres among categories of government ownership or programs within the GHRA, 1990 and 2012[1].*

Agency or Program	1990	2012	Change[2]
Wisconsin DNR fee title – 6 large properties	7,281	8,127	846
Wisconsin DNR fee title – small properties	3,930	7,822	3,892
Wisconsin DNR easements	3,525	4,955	1,430
USFWS fee title - HNWR	14,771	15,417	646
USFWS fee title - WPAs	2,084	3,363	1,279
USFWS contracts – PFW	68	142	74
USDA easements – WRP	1,763	4,769	3,006
USDA contracts – CRP	5,255	9,196	3,942
Remaining Private Lands	102,450	119,614	17,164
Total	**141,127**	**173,405**	**+32,278**

[1] Includes water, cattail, hydric grass, shrubs, and wetland forest classes.
[2] Change in terms of gain in 2012 (i.e. 2012 acres–1990 acres).

Table 14. *Change of important wetland (cattail + water classes) acres among categories of government ownership or programs within the GHRA, 1990 and 2012.*

Agency or Program	1990	2012	Change[1]
Wisconsin DNR fee title – 6 large properties	4,021	4,298	277
Wisconsin DNR fee title – small properties	1,149	1,491	342
Wisconsin DNR easements	995	1,578	583
USFWS fee title - HNWR	11,581	12,298	717
USFWS fee title - WPAs	550	1,219	669
USFWS contracts - PFW	16	21	5
USDA easements - WRP	370	1,539	1,169
USDA easements - CRP	778	344	- 433
Remaining Private Lands	41,230	45,620	4,390
Total	**60,689**	**68,408**	**+7,719**

[1] Change in terms of gain in 2012 (i.e. 2012 acres–1990 acres).

Wisconsin DNR Lands

Approximately 27,479 acres of Wisconsin DNR managed lands were present in 2012 within the GHRA: 10,159 acres on six large properties, 10,933 acres of fee title ownership of smaller properties (95% of them managed by the Bureau of Wildlife Management), and 6,387 acres of purchased easements (72% of them secured through the GHRA program). The large Wisconsin DNR properties were dominated by large marshes, with little active management. Habitat restoration was much more active on the easements and small acquisitions than on these large properties.

The area of total grasslands increased from 1990 to 2012 on all three categories of Wisconsin DNR managed lands, a collective gain of 6,158 acres; most of this gain took place on the small fee title acquisitions (Tables 10 and 11). Similarly, there was a gain in the area of upland grass in all categories of Wisconsin DNR managed lands (collective gain of 3,003 acres), especially on small fee title acquisitions. About half of the upland grassland gains (56%) and total grassland gains (45%) in the GHRA took place on Wisconsin DNR lands. The area of hydric grass increased overall by 3,155 acres on Wisconsin DNR lands, but declined on the six large properties because of shrub invasion there.

The area of wetland types increased for all Wisconsin DNR land categories according to several groupings of wetlands. This amounted to collective gains of 1,202 acres of important cattail and water classes, 3,110 acres of target wetland types (water, cattail, and shrubs), and 6,168 acres of total wetlands (Tables 12-14). The proportional increase in “cattail+water” wetlands was much greater on the Wisconsin DNR easements (59% of the 1990 base) than on the small fee title acquisitions (30% of the base) or large properties (7% of the base). More total wetland acres existed on Wisconsin DNR lands than on federal lands or lands in government programs in 2012; this was mainly due to the large shrub acreage on the large Wisconsin DNR properties.

USFWS Lands

There was a net loss of hydric grass and total grass on HNWR because of the flooding of an impoundment that was hydric grass in 1990 and some cattail invasion by 2012. While there are many upland grass fields at HNWR, most were stable over time and there was only a minor gain of 81 acres of upland grass. Seven of the nine WPAs in the GHRA were purchased after 1990 and acquisitions increased the size of the other two WPAs. Establishment of grass cover on these new USFWS lands resulted in a gain of 309 upland grass acres and 803 total grass acres in the GHRA. The USFWS PFW program was also responsible for adding 72 acres of total grass on 23 properties, most of it hydric grass.

The area of cattail+water wetlands, target wetland types, and total wetlands increased on HNWR, WPAs, and PFW lands. The increases on WPAs showed a doubling of target wetland types (+122%) and total wetlands (+96%) over 22 years. More cattail+water wetland and target wetland acres existed on USFWS lands than on state lands or lands in government programs in 2012; this was mainly due to the large cattail acreage on HNWR.

USDA Program Lands

The WRP did not exist when the original land cover classification was completed in 1990, providing an opportunity to evaluate the full impact of this program since its implementation by comparing the 1990 land cover to the land cover present in 2012. By 2012, a total of 5,144 acres of WRP easements existed within the GHRA. The CRP was very active in the GHRA from 1990 to 2007, the last time CRP location data were available. CRP contracts within the GHRA for grass totaled 10,894 acres in 1990, peaked at 15,139 acres in 1994, then declined to 13,755 acres by 2007. Overlay analyses of these 2007 contract boundaries with 2012 land cover indicated that 24% of these fields left the program (i.e. were converted back to agricultural crop production) from 2007 to 2012, a decline to 10,454 acres in 2012. This is a complete loss of the grassland gain listed in CRP contracts over the course of the GHRA program, to a level 4% below the 1990 starting point. We tracked 23,319 acres within boundaries of CRP contracts for all conservation practices (i.e. not just targeted at grass cover) over the course of the 22 years.

Total grassland area increased from 1990 to 2012 on lands under both USDA programs, a collective gain of 7,125 acres; most of this gain came from the CRP (Tables 10 and 11). There were 1,081 acres of grass in 1990 within what would be WRP boundaries (26% of the WRP area), before they were entered into the program. This emphasizes the importance of looking at pre-existing conditions to evaluate true grassland gains. Because the WRP targets wetland areas, 94% of its grassland gains came from hydric grass and very little from upland grass. More upland grass, hydric grass, and total grass acres existed in 2012 on lands under USDA programs than on state or federal lands. More hydric and total grasslands were gained over the 22 years from USDA programs, especially the CRP, than on state or federal lands.

WRP easements were responsible for greater gains in cattail+water wetlands (+1,169 acres) and targeted wetlands (+1,566 acres) than on any other public land or program. There were losses in cattail+water wetlands and only very minor gains in targeted wetlands on CRP contracts. There were more total wetlands gained through USDA programs than on state or federal lands. The large gain in total wetlands on CRP contracts came mainly from gains in hydric grasslands.

Other Private Lands

Private lands outside of these public programs (“other private lands”) showed an alarming loss of grasslands from 1990 to 2012 (Tables 10 and 11). These private lands lost 6,893 acres of total grasslands, contrasting the gains on all public lands and programs (except the impoundment flooding at HNWR). The loss of upland grass was even greater on these private lands (-8,665 acres), and was responsible for the overall loss of upland grass across the GHRA. However, there was a gain of hydric grass (+1,774 acres) on these private lands. In spite of the losses, 10,393 acres of upland grass and 50,447 acres of total grass still existed on these private lands in the GHRA in 2012.

The opposite pattern occurred for wetlands. There were gains in all three groupings of wetlands on other private lands in the GHRA over 22 years. The wetland gains on these private lands exceeded those on public lands or USDA easements and accounted for 57%, 64%, and 53% of gains in the GHRA for cattail+water wetlands, targeted wetlands, and total wetlands (i.e. cattail, water, shrub, hydric forest, and hydric grass classes), respectively. The total area in wetlands on these private lands in 2012 dwarfs that on all government lands and programs because of the inclusion of large open water lakes. The nine largest lakes in the GHRA had a combined area of 30,184 acres in 1990 and 29,032 acres in 2012, ranging in size from 161 to 12,340 acres/lake. When these lakes are excluded from the summaries, there were still more wetland acres on these private lands than any other public lands or programs in 2012.

Discussion

The desired overall accuracy for land cover mapping using remote sensing data is generally accepted to be between 60% (Liu 2011) and 85% (Anderson et al. 1976), with accuracy goals varying according to the number of classes, spectral complexity within and among classes (Van Niel et al. 2005), ROI sample sizes, temporal range of images to capture vegetation variation and growth stage (Foody and Mathur 2004a), and clarity of transitions between natural landscape types (Colditz et al. 2011). The overall map accuracy of our 15-class classification was 81%, and increased to 86% after consolidation into eight classes. We feel that the six dates of Landsat images spread over six months that we used were adequate for capturing temporal variation. After consolidation into eight classes, our ROI sample sizes appeared adequate, ranging from 128 to 617/class (mean=354); the exception was water (n=74), which tends to be spectrally distinct from other land cover classes, and in our study had the highest accuracy (97%) of any class. Shrubs and non-row agriculture remained challenging to classify. Although separability ratings between our eight classes were high overall, those involving shrubs and non-row agriculture (i.e. alfalfa [*Medicago sativa*] and pasture) were among the lowest for our study. Variability of the vegetation within the classes themselves (e.g., height and density of shrubs, ground vegetation between shrubs, variety of vegetation present on pasture, etc.) probably influenced this confusion. Review of the confusion matrix showed that these classes were most often misclassified into classes they were structurally similar to. While we lack independent estimates of variation of the classification accuracy, the five runs of the cross-validation suggest reasonably small variation. Overall accuracy ranged only 6.2 % and 5.3% among the five runs of the 15-class and eight-class schemes, respectively. The difference between total grass coverage of the 15-class and eight-class maps shows that a small change in overall accuracy can have an impact on the land cover composition of the map (Tables 5 and 6).

A review of the confusion matrix in the 15-class classification found that half of the misclassifications within both the idle grass and canary grass classes were confusion between the two classes themselves. This indicated higher accuracy to identify pooled grassy vegetation but lower accuracy in distinguishing between the grass types. In our project, the accurate identification of general grasslands was more important than separation of grass subclasses. In other situations, increasing map accuracy may not be worth the cost of limiting map usefulness by eliminating subclass distinctions. The goal of high overall accuracy must be carefully balanced with potential uses of the classified map.

The existence and areal coverage of wetlands, especially open water, on the landscape is a function of precipitation received preceding satellite data collection. Precipitation in Wisconsin during 1990 (E.J. Hopkins, Wisconsin State Climatology Office, unpublished data) was above the long-term mean (1895-2012) for April-July (+18%), March-August (+27%), and January-September (+19%). Conversely, Wisconsin was drier than average in 2012 for April-July (-3%), March-August (-8%), and January-September (-18%). The vast majority of open water in 1990 occurred in basins over 40 acres in size in both the GHRA (95% of total open water) and control area (88%). When calculating change over time, these large, stable areas of open water (lakes, major rivers, or impoundments) cancel each other out. The remaining changes (contraction in 2012 from the edges of the 1990 flooding) are real, but not the result of GHRA management. They reflect natural fluctuation in water conditions between the two years picked to document land cover change. The combined area of open water in basins over 40 acres contracted in both the GHRA (-9%) and control area (-12%) from 1990 to 2012, as expected with the drier conditions in 2012. The combined area of open water in basins under 40 acres declined 50% on the control area but only 9% in the GHRA; the smaller basins were expected to contract at a greater rate than larger basins. Open water changes seen in these smaller basins in the GHRA included wetland restoration, which may have countered natural declines in open water wetlands. Wetland restorations by GHRA managers usually were small, shallow basins that were classified as invading cattails rather than open water in the dry conditions of 2012. In general the natural dynamics of cattail and shrub wetlands reflect more long-term water conditions than in-year precipitation. The period of 1990 to 2012 had a mean annual precipitation 5% above

normal (E.J. Hopkins, Wisconsin State Climatology Office, unpublished data), which may encourage the spread of cattails. These natural wetland dynamics emphasize the importance of looking at the net difference in wetland cover between the GHRA and its control area in estimating the impact of GHRA management.

Comparisons between the land cover present in 1990 and 2012 yielded some interesting, apparent trends. However, several differences between the 1990 and 2012 classification schemes need to be considered. Several of the classes used by Polzer (1992) were not present in our 2012 classification due to a lack of reference data, so reclassification and consolidation of the 1990 classes could have influenced the comparison between years. Also, the comparable class accuracies were considerably lower in the 1990 classification than those in 2012, possibly related to the use of fewer image dates and less advanced software options in 1990. These accuracy differences can influence the outcome of comparisons between years. An exception was reed canary grass, which had accuracies of 88% in 1990 and 71% in 2012; the wetter conditions in 1990 may have promoted more robust growth, with a clearer spectral signature than in the drier conditions of 2012. The 1990 map's input of roads post-classification over-estimated road coverage, which was pooled into the developed class for the 2012 comparison. Although developed coverage increased in 2012, this was likely underestimated by the 1990 bias. This bias makes evaluation of changes in development very speculative and also biases low the coverage of classes adjacent to the 1990 roads to an unknown degree.

The greater forest cover within the control area compared to the GHRA is due in part to the large area of forest readily seen in the northwest corner of the control area (Figure 5); this concentration of forest cover has the potential of being a poor control to forest cover changes if these larger forest dynamics differ from those in the small woodlots on the GHRA. The increase in woody vegetation types (forest and shrubs) across the study area could be due to natural or socioeconomic factors. Brown (2003) reported increases in forest cover on private lands in the upper Midwest and found evidence of both factors. While we found that both forest and shrub cover gains came mostly from agriculture classes (idling farm land), the gains in shrub cover also indicated plant succession (invasion of grassland) to a more woody vegetation structure in the GHRA. There was a net shrub gain in previously forested areas, however, running counter to natural succession and suggesting human activities (cutting). Management (burning or cutting) to counter woody plant succession was a challenge on public lands and believed to be minimal on private lands. A gain of forested coverage runs counter to the GHRA goals for increasing grassland bird habitat. The negative net changes of both upland and wetland forest types on GHRA vs. control areas (i.e. less gains in forested coverage on the GHRA than the control area) could have been influenced by contacts from GHRA managers, but more likely reflects private landowner efforts opposed to this increasing forest cover in the open GHRA landscape or greater afforestation efforts on the control area; this could be more evidence that the more heavily wooded control area, though directly adjacent to the GHRA, is a poor control for human-forest dynamics in the GHRA. Woody shrubs are important for ring-necked pheasants (*Phasianus colchicus*), a target bird species of the GHRA (Gates 1970, Gatti et al. 1989). Shrub replacement of forest cover on the landscape is viewed as a positive change, but their invasion into herbaceous wetlands and grasslands is cause for concern because the more open habitats are preferred by obligate grassland bird species' nesting (Murray et al. 2008, Graves et al. 2010) and duck survival (R.C. Gatti, Wisconsin DNR, unpublished data). More frequent land cover classification could help identify which successional processes are taking place and evaluate if these changes are in line with desired management goals.

In spite of lacking 2012 CRP data from the USDA, we were able to estimate conversion of 2007 CRP contracts back to agriculture using remote sensing; however, we missed any contracts added to the CRP after 2007. But given the sharp decline in CRP contracted acreage from 2007 to 2012 collected from county tabulations, it is likely that the number of new contracts was minimal at best. Although CRP records showed that 10,894 acres of contracts targeting grass existed in 1990, only 55% of this area was identified as grass cover in the 1990

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classification, likely because young plantings had not yet established as grass vegetation. The acreage of grass on lands under CRP contracts in 2012 exceeded the total grassland contract area in 2012, the excess coming from grass cover on fields targeting tree establishment. These examples demonstrate the problem of using tabular data rather than field data in assessing land cover change.

After 22 years of effort, the GHRA program was not able to achieve its goal of 20,000 newly restored grassland acres. Total grassland gains on state and federal lands and programs totaled only 13,984 acres (70% of the goal). If the CRP had maintained its gains over the past 22 years, total grassland gains could have approached 18,600 acres (93% of the goal). Nonetheless, grassland gains on government lands and programs were offset by significant losses on other private lands, reducing the program grassland gain to 35% of its goal. The status for upland grass was even worse in the GHRA; combined government lands and programs gained only 5,427 acres of upland grass, which turned into a 3,238-acre deficit after inclusion of upland grass losses on other private land. Grass cover on upland soils appeared to be preferred over that on hydric soils for conversion to croplands. The GHRA program was based on the premise that large scale habitat restoration could be accomplished through contracts and easements on private lands via economic incentives to supplement fee title acquisition (Crossley et al. 1990). But these incentives could not compete with high commodity crop prices (unforeseen in the 1990s), which motivated private landowners to convert grass cover to agriculture, including nonrenewal or termination of CRP grass contracts (Kiger 2009). The failure of economic incentives to provide wildlife habitat reliably at a broad scale has been documented before (Hoskins 2005) and was a conclusion of Leopold (1939), though the scope of recent market forces and government subsidies seems unprecedented (Babcock 2012, McElroy 2012). While short-term contracts worked for many years in the GHRA, in the end they proved undependable.

Another GHRA goal was to have 38,600 acres in grasslands on the landscape. In spite of the grassland losses on private lands from 1990 to 2012, over 82,000 acres of grassland (2.1 times the goal) and 20,421 acres of upland grassland (53% of the goal) existed in 2012. In fact the goal was already met before the program began; 75,054 acres of total grassland (194% of the goal) and 23,524 acres of upland grass (61% of the goal) existed in 1990 based on the satellite data. In fact the goal was already met before the program began; 75,054 acres of total grassland (194% of the goal) and 23,524 acres of upland grass (61% of the goal) existed in 1990 based on the satellite data. Additionally, grasslands classified from satellite data were more than small patches of grass in odd areas. Over 54% and 71% of the grassland acreage in the GHRA in 1990 and 2012, respectively, were in polygons >20 acres, the GHRA management guideline for grassland establishment. Most of this grassland acreage existed on private lands outside of government lands and programs, which was unknown from tabular files. The 1990 satellite land cover classification totaled 17,851 acres of total grassland on government lands and programs in the GHRA, close to the 18,600 acres believed to exist in 1990 from tabular file data. This is another example of the efficiency of using remote sensing vs. tabular file summaries to set and monitor management goals for land cover.

Evaluating the GHRA accomplishment of restoring 11,000 acres of wetlands is a difficult task. Remote sensing determined that between 1990 and 2012 there was a gain of 7,719 acres of water and cattail classes in the GHRA and a wetland gain of 17,744 acres when wetland shrubs were included. The latter figure exceeds the GHRA wetland goal. The real benefit of the program was what was accomplished, compared to what might have happened, as seen on the control area; this net gain was even greater than that seen only within the GHRA because of wetland loss in the control area. The largest gains in wetlands among government lands and programs in the GHRA came on WRP easements and large Wisconsin DNR properties (when shrubs were included). However, private lands accounted for 57% of the gains of cattail+water wetlands and 64% of the gains of target (cattail+water+shrub) wetland types. The importance of wetland gains on these remaining private lands was unexpected and the reasons behind them need further research.

Wetland quality is not easily captured via remote sensing. The ideal wetland restoration (or gain) for dabbling ducks would be an area with a mix of open water and emergent vegetation, well interspersed ("hemi-marsh") across the basin (Weller and Spatcher 1965, Murkin et al. 1982). Open water is not as preferred as this hemi-marsh, and dense, monotypic, cattail wetlands are of limited value. The cattail class we identified from Landsat 7 data does not have the resolution to separate these qualitative categories of cattail densities and includes both monotypic and mixed cattail/open water areas. However, 30% of the gain in area covered by cattails came from agricultural lands, which is a positive tradeoff. Additionally, these cattail areas could be flooded into a more preferred state under years of wetter conditions than the dry conditions of 2012. This lack of quality resolution via remote sensing may be solved by data from other high resolution commercial satellites or Landsat 8, with the additional 15-m panchromatic band, improved spectral resolution, and fully-functioning data collection (i.e. no SLC failure).

Ongoing monitoring of land cover change is an important tool in wildlife management. The availability of satellite imagery for little or no cost, improvements in image interpretation software, and the need for cost-effective ways of mapping large areas of the landscape make remote sensing an attractive option for land cover classification. Changes in coverage of specific vegetation types, as well as generalized trends and comparisons of managed and non-managed areas can be evaluated quickly by comparing classified maps of a region spanning different time periods. Comparisons of the GHRA land cover present in 1990 and 2012 showed that coverage of natural land cover classes have generally increased throughout the study area, but the loss of grassland and expansion of shrub and cattail coverage, particularly on private lands, should be further evaluated to determine potential causes. Future land cover mapping could focus on more detailed spatial resolution or differentiated grassland and wetland classes to better assess the quality of habitat for wildlife.

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